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ARTIFICIAL REEFS: A REVIEW & CRITICAL PERSPECTIVE

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ABSTRACT
This paper provides a summary of the history and development of artificial reefs from their beginnings as a tool of the artisanal fisherman to their uses in fisheries management and environmental mitigation of pollution events. Artificial reefs have been deployed in 22 countries worldwide (Seaman, 2002) and have been used for a wide range of roles, yet the scientific literature regarding artificial reef research is still fraught with problems and controversy. In an effort to provide a strong base for future research this paper reviews a small cross-section of the ecological studies carried out on artificial reefs. The review found that lack of experimental replication was a consistent problem, with small sample sizes resulting in low statistical power. Additionally pseudoreplication of data was deemed to be an issue because of the lack of independence between sample sites. The studies reviewed tend to be limited by the economics and legal limitations of artificial reef deployment, and so in all but two of the studies artificial reefs deployed for another purpose were used in the experiment. In the future, replication is the key to obtaining meaningful quantitative data in artificial reef research. As with any field-based experiment certain assumptions and generalisations must be made in order to maintain an economical and achievable experimental design. However, this should be recognised and careful consideration of how it will affect the results should be undertaken by the researcher(s).

INTRODUCTION
Artificial reefs, as defined by Seaman and Jenson (2000), are effectively objects of natural or man-made origin, deliberately placed on the sea floor in order to influence some aspect of the marine resources in that area. These can consist of anything, from derelict vehicles, tyres or concrete blocks, to quarried rock or timber, and can be seen to have a wide variety of possible uses and impacts, which must be carefully considered before the deployment of the reef.

The aim of this short paper is to provide a review of the scientific literature published on artificial reefs and in particular the associated ecological impacts. The paper will provide a summary of the current level of scientific knowledge on artificial reefs and their uses worldwide. It will then assess and critically review a sample of the small number of studies within the literature which investigate the impacts of artificial reefs upon mobile macro-fauna with regard to experimental design. In particular this review will examine the problems associated with achieving adequate replication of samples, pre-deployment research, quantification of results and cost effectiveness in artificial reef research.

From this base artificial reefs can be examined within the context of whether or not they "make a difference" both ecologically and economically. In addition, the review will critically assess previous artificial reef research and examine the experimental criteria that should be considered in future studies.

SUMMARY OF HISTORICAL AND PRESENT APPLICATIONS
Historically artificial reefs have been documented in various forms as a tool of the artisanal fisherman who, observing that fish tend to aggregate in areas where the sea floor is heterogeneous in some way (e.g. rocky), learned to mimic this natural heterogeneity by dumping materials onto the sea floor (d'Cruz *et al.*, 1994). This is demonstrated by the fishermen of Japan (Meier er al., 1989) and the West African nations of Benin and Côte d'Ivoire. The fishermen in West Africa practise a traditional method known as Acadja, which involves placing a dense mass of woody branches into shallow water (~1m depth) of a lagoon. The acadja provides a heterogeneous environment, which not only attracts and aggregates fish, but also provides an ideal site for reproduction and growth of many fish (Hem and Avit, 1994). Although artificial reefs have a long history they were first used in the Far East (Kim, 2001) and the developing world their first deployment in the western world was in the 1950s, where reefs were deployed by the US Navy to enhance recreational fishing in California (Dreysher *et al.*, 2002).

In Europe the use of artificial reefs commenced in the 1960s in Monaco for conservation purposes. The reefs were deployed in 1979 in the marine reserve of Monaco (established in 1976). Designed to halt the progressive destruction of seagrass meadows, these reefs were deployed close to the shore and were observed to have developed a typical Mediterranean rocky reef fauna (Jenson 2002). A second reserve area was then designated in 1986, and artificial reefs were deployed with a view to cultivation of *Corallium rubrum* (Linnaeus), the red coral, with the coral being transplanted from a natural population and attached to cave walls in the reef with epoxy resin (Jenson 2002).

From this beginning interest in artificial reefs in Europe has increased, with the deployment of Large Artificial Reef Units in France since 1985 (Charbonnel *et al.*, 2002), the construction of the Loano artificial reef in the Liguarian Sea, Italy in 1986 (Relini *et al.*, 2002) and the construction of the Poole Bay artificial reef in the United Kingdom in 1989 (Jenson 2002). A total of nine European Union nations have licensed artificial reefs in their territorial waters, including the United Kingdom, France, Spain, Poland and the Netherlands, and several countries both within the EU and outside it have expressed interest in Artificial Reefs, including Ireland, Denmark, and Norway.

This interest in artificial reef technology has provided a wide scope for scientific investigation in Europe, and with the foundation of the European Artificial Reef Research Network in 1991, through funding by the European Commission (Jenson, 2002) a clear development of artificial reef science within Europe is underway, based on the pioneering studies of the last 30 years.

Outside of Europe 22 countries have artificial reefs deployed in their territorial waters, including the United States, Canada, India, and probably the world leader in artificial reef technology Japan (Grove *et al*., 1994). This is based on the reports of the international Conferences on Artificial Reefs and Related Aquatic Habitats (CARAH) in 1991 and 1999 (Seaman, 2002), so the number may have increased or declined since then.

Worldwide artificial reefs serve many purposes, from fisheries enhancement and protection to environmental mitigation of pollution to tourism and as such provide a wide range of opportunities for the scientific study of their impacts *in situ*. However in order to be adequately studied any artificial reef must have a series of clearly defined goals, with which assessment can be made.

Fisheries Protection and Enhancement

As a fisheries protection tool the artificial reef has proved to be fairly popular across the globe. In Hong Kong, for example, artificial reefs are being deployed within designated marine-protected areas (MPAs) in an attempt to combat the depletion of fish stocks. The primary goals of the Hong Kong projects are to increase the depleted biomass and to re-establish populations of high-value commercial species in an effort to mitigate against the effects of over-fishing (Pitcher *et al*., 2002).

Investigation of the use of decommissioned oil-rigs as artificial reefs has also been carried out with a particular emphasis on the impact on exploitable fish-stocks. This is exemplified by the North Sea Ekofisk oil field, which was assessed as a potential offshore reef site at the beginning of this century (Cripps and Aabel, 2002). In their Environmental Impact Assessment it was concluded that the use of the reef for protection of fish stocks could be of benefit, by providing refuge and food to juvenile fish, allowing increased recruitment to the exploitable populations from the reef. However, in contrast, a review by Sayer and Baine (2002) provides evidence that in the North Sea the rigs to reefs strategy would have little positive impact on fisheries and as such could be both an economic and ecological "white elephant."

The review by Sayer and Baine (2002) examined the potential for a North Sea rigs to reefs programme in comparison with the current programme being carried out in the Gulf of Mexico. It concluded that the environmental conditions in the North Sea differ greatly from the Gulf of Mexico where warm, shallow water combines with the high levels of inshore components to the oil production infrastructure, providing a rigs to reefs programme which mainly services the recreational fishing and diving markets. Additionally it was concluded that the loss of fishing exclusion, provided by the operational rigs in the North Sea, would adversely impact upon the commercial fisheries and thus negate the small increase in habitat which would become available through the deployment of decommissioned oil and gas rigs as artificial reefs.

Artificial reefs contribute to the enhancement of fisheries in two ways according to Seaman and Jenson (2000), firstly by attraction of mobile organisms to the reef, and secondly through habitat enhancement, which will in turn cause an increase in biomass at the site. However, this view of the reefs as additional habitat does not come without controversy over whether the reef actually does increase the productivity of an area, or whether it will merely act as an attractant, leaving other areas depauperate; the so called attraction- production controversy (Osenberg *et al*., 2002). It is likely this is merely an effect of scale as increased fish populations are observed around artificial reefs (d'Cruz *et al*., 1994; Lin and Su, 1994) and there is significant evidence that the fish populations of artificial reefs do contribute to the larval pool of reef fish in the surrounding area (Stephens and Pondella 2002).

Environmental Mitigation and Remediation

The use of artificial reefs as a form of mitigation measure against pollution has become increasingly important, and has thus provided the backdrop for much of the research carried out on artificial reef ecology. This particular use of artificial reefs has been applied mainly in the state of California, USA, where warm water outputs from Nuclear Power Stations proved detrimental to the growth of the giant kelp, *Macrocystis pyrifera* (Linnaeus), and thus to the associated ecosystems on the Californian coast. The use of artificial reefs, as a form of on-site mitigation resulted from the high costs associated with the alternatives, including re-routing of the discharge pipes, and the installation of salt water cooling towers. Examples of this include the Pendleton Artificial Reef (Grant *et al*., 1982) and the 9 hectare experimental reef placed in the vicinity of San Onofre Nuclear Generating Station, Southern California. The San Onofre reef consists of 56 separate modules and provides a preliminary study, on which a further 61ha reef will be designed and deployed (Deysher *et al*., 2002).

Artificial reefs have been deployed in the Republic of Maldives as a means of mitigating against damage done to natural reefs by coral mining, in particular around Malé Island. A study by Clark and Edwards (1994), describes the process of deployment of artificial reef structures to an experimental site on a reef flat in the Maldives. The findings of that study show a clear enhancement of the reef-flat ecosystem, with increased fish populations around the reef site, and successful recruitment and transplantation of coral species onto the reef modules. Their study, therefore, demonstrated the ability of artificial reefs in mitigating damage to important ecosystems, particularly in places like the Maldives, which rely heavily on their coral reefs for tourism, fisheries and coastal defence.

Another use of artificial reefs as a mitigation measure that has been investigated in the form of biofilters deployed in conjunction with fish farms. As the organic and nitrate output of fish cages is high, and much of this detritus sinks to the sea floor directly below the fish cage, a reef may provide a mitigation measure, by providing a substrate for biofouling and a heterogeneous environment which will attract many species capable of utilising the detrital rain in some way. This has been investigated in Israel (Angel and Spanier, 2002), and although the reef provided no change in the organic content of the water during the study period, it did increase the abundance of numerous species beneath the fish cage, mitigating the decline in biodiversity associated with fish cages.

On the whole the use of artificial reefs as bioremediation and mitigation tools is both a difficult and expensive solution. Large amounts of research need to be carried out, pre-deployment, followed by a limited experimental deployment, prior to full deployment. This is required to develop a reef which exhibits similarity to the receiving environment or surrounding reefs (Ambrose, 1994). Also these problems can be compounded by the complexity of the receiving ecosystem and direct restoration is not always possible (Pratt, 1994). As such, the rules of island biogeography are often simply applied, with the largest reefs possible being used, in order to provide a high level of habitat complexity.

Recreational Uses

The use of artificial reefs for recreational purposes has been popular, and has provided a strong socio-economic goal in their design Artificial Reefs have been used to enhance recreational fisheries; to provide attractions to SCUBA divers, e.g. the wreck of the Scylla, UK; and to influence the physical environment, improving wave formation for surfers.

Some of the first reefs to be deployed for recreational purposes were at Paradise Cove and Redondo Beach (both in California). These reefs, consisting of old car bodies and trams, respectively were sunk by the U.S. Navy in 1958 to support sport fisheries (Deysher *et* al., 2002). However the majority of reefs tend to have numerous goals, aside from attracting recreational users, but it is worth noting that this use is important, needing careful consideration in reef planning and licensing, as it can provide an important "market" for an artificial reef.

The recreational use of reefs often goes hand in hand with their use in environmental mitigation and conservation. One way that this objective is met is through the relief of natural reef sites, from the stress and disturbance factors associated with recreational use by humans (Abelson and Shlesinger., 2002).

Scientific uses of Artificial Reefs

The development of Artificial Reef programmes worldwide has fuelled scientific research into their uses, and impacts upon the environment. Thus effectively the scientific uses of artificial reefs goes hand in hand with meeting objectives of higher economic value, e.g. fisheries protection. However, there have been artificial reefs built worldwide with the primary goal of providing an experimental structure. Examples of these scientific reefs include the Poole Bay artificial reef and the Loch Linnhe artificial reef, both in the United Kingdom.

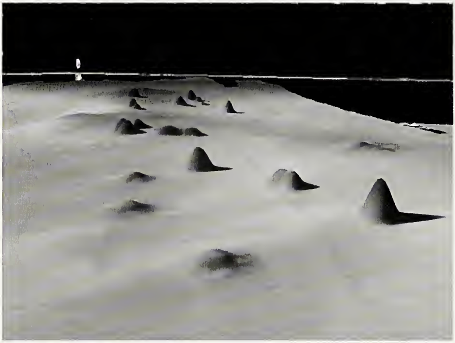
The Poole Bay artificial reef, deployed in 1989, was designed as an experiment on the impact of stabilized Pulverised Fuel Ash (PFA) blocks upon the environment. These blocks were composed of PFA waste from coal fired power stations and bound in a cement and aggregate mixture. Continuous monitoring was then undertaken to establish if any leaching of heavy metals from the blocks was occurring, and to observe the biotic colonisation of the reef (Collins and Jensen, 1997).

In July 1998 scrap tyre reef modules were deployed at the Poole Bay reef, alongside the PFA reefs, with the tyres being formed into definite structures, and filled with concrete. These modules were then deployed and monitored at bi-monthly intervals by SCUBA divers, who again studied the biological colonisation of the area and also the fate of the heavy metals bound within the scrap tyres. The results were presented in the form of an Environmental Impact Assessment (Collins *et al.*, 2002) and show a rapid colonisation of the reef modules by biofouling organisms, with a successional change from the initial algal colonists towards a hydroid dominated community. The new community included some bryozoans, ascidians, barnacles and worms and, as a result, an increase in mobile grazing species. Heavy metal leaching was demonstrated to have significant effects on biofouling organisms, in particular on the tyre reefs.

The Loch Linnhe artificial reef was licensed in 2001, for a proposed 24-module reef complex, of some 42,000 tonnes at a site on the east side of the island of Lismore (Sayer and Wilding., 2002) (Fig. 1), with deployment commencing in April 2003. Later the reef complex was redesigned to consist of 42 reef modules, at a weight of around 25,000 tonnes. Prior to the deployment of the Loch Linnhe artificial reef research was carried out at the proposed site and involved a sonar survey of the seabed, analysis of current speeds at the site, granulometric analysis, analysis of sediment redox potentials and sampling of the fauna associated with the site (Wilding and Sayer, 2002a). In addition, a detailed study of potential construction materials was undertaken, in order to select a construction material which would be environmentally safe and physically robust, at low production cost (Wilding and Sayer, 2002b).

Fig 1 Map showing the location of the Loch Linnhe Artificial Reef, within the wider Lynn of Lorne area

Fig 2 Multi-beam sonar image of the Loch Linnhe Artificial Reef, showing the two groups of six modules and the larger multi-drop reef module.



In its present form the Loch Linnhe artificial reef consists of five groups. Each group consists of six reef modules, three of which are constructed from complex blocks, and three constructed from simple blocks. Reef module size is relatively standard, at around 4200 blocks, and in total the design provides a high level of replication within the reef site. Additionally one multi-drop, consisting of three deployments of complex reef blocks has been made (Fig 2).

The Loch Linnhe artificial reef provides huge potential as a research tool. However at present its use is at a very early stage. It has been observed to provide new hard substrata with a significantly higher level of geometric complexity than the natural reefs in the surrounding area (Rose 2005). This increased habitat complexity has the potential to support higher levels of animal abundance than comparable natural reefs, and this has been observed in the wrasse species *Ctenolabrus exoletus*, Linnaeus, and *Crenilabrus melops*, Linnaeus, and in the crab *Necora puber* (Linnaeus) (Hunter, unpublished data). However the reef has also been observed to collect phytodetritus around the reefs edges and a decreased level of sediment oxygenation in area around each reef module (Wilding, 2006).

REVIEW OF LITERATURE

In order to adequately review a cross section of the literature related to artificial reefs, five papers were selected from peer-reviewed literature to be examined. These provide a typical sample of some of the research which has been carried out on artificial reefs. In particular these papers all deal with the effects of artificial reefs on fish and mega-invertebrate assemblages, either through comparison of artificial reef complexity (Charbonnel *et al.*, 2002), comparison of artificial reefs with natural reef and control sites (Fabi & Fiorentini, 1994; Fujita *et al.*, 1996) or simply by examination of the colonisation or aggregation of fauna upon the artificial reefs (Bortone *et al.*, 1994; Jensen *et al.*, 1994).

Comparison of Artificial Reef Complexity

The first paper considered was a comparison between two Large Artificial Reef Units (LARUs), of different complexity which were deployed in a Marine Protected Area on the French Riviera, at 27m depth (Charbonnel *et al.*, 2002). Deployment occurred between 1986 and 1987 with each LARU consisting of nine large concrete slabs, with void spaces occupying $158m^3$. In the experimental (complex) unit these void spaces were filled with $37m^3$ of building materials, piled up randomly by divers, in 1991, whereas the control (simple) unit was left untouched.

Data collection was by visual census, carried out by SCUBA divers, and each module was censused 17 times between February 1987 and July 1989, and then 20 censuses, after the manipulation of the experimental LARU, between October 1997 and July 1998.

The most striking issue within this study is the lack of replication. Only one experimental site and one control site were used, with data being collected both before, and several years after the manipulation of the control site by divers. This relies on the two sites being completely identical prior to the manipulative treatment, (Hurlbert, 1984), and unfortunately the study in question suffers two major problems because of this. Firstly there are relatively few samples taken from each unit prior to the manipulation by divers (only 17 over a one and a half year period) and secondly six years passed between the manipulation of the experimental unit and the second sampling period. This lack of sampling effort over time leaves the study in a weak position, because it is simply a comparison of two isolated sites, and so it is questionable whether or not the study can be used to draw any conclusions on the effect of reef complexity on faunal assemblages outside of the study site.

Pre-deployment research in this study is not a major issue because it is a test of the manipulation of the experimental site, and data were recorded prior to this occurring. However, as already stated the issue largely comes down to whether the number of samples taken before manipulation is sufficient to prove the two sites to be identical. Additionally the authors have supported their findings by examining work carried out by other authors, as well as carrying out work themselves, on fish assemblages on a Mediterranean artificial reef, and rock substratum, helping to support the study.

Quantification was also somewhat problematic within this study, as the main form of data collection was by SCUBA divers carrying out an unspecified visual census. No information on census strategy was given, which makes reliability difficult to assess. Alongside this the information on biomass was estimated from the relative abundance observed, which provides a very crude estimate, onto which statistical tests were applied.

Many of the issues of experimental design seem to originate from the unreplicated treatment. This may well be an economic issue, with regard to the cost of LARUs, and their primary goal being the conservation of *Posidonia oceanica* beds, leaving scientific study as a secondary goal, but it is clear that more care should have been taken in the data collection and analysis to overcome these issues. As a result the study is fundamentally flawed and adds little to the literature.

Comparison of Artificial reefs, Natural reefs and Control Sites

In comparing artificial reefs with other sites, including natural reef and control (sandy bottom) sites, two papers were examined. The first of these was a comparative study carried out on the Okama artificial reef, comparing it with a natural reef and a sandy-mud bottom site off northern Japan (Fujita *et al.*, 1996). The study was carried out using a bottom trammel net, on the three sites, each at a depth of 130m, over a six year period from May 1987 to March 1993. Between May 1987 and September 1990 24 samples were collected every two months at each of the three sites. Then from May 1991 to September 1991 ten additional samples were collected at the artificial reef site, and this was continued every two months from January 1992 to March 1993. As a result of this a large number of samples were taken using standardised equipment. The study, however, is of a non-replicated design examining three discrete sites, one artificial reef, one natural reef and one control site. Therefore, the results showing a greater level of fish abundance and species composition at the artificial reef, can only be used to draw conclusions about the isolated study sites. In order to allow meaningful conclusions to be drawn about differences in fish abundance and species composition to be drawn between artificial and natural reefs, a number of replicate sites of each treatment (artificial reef, natural reef and control) need to be investigated (Hurlbert, 1984).

In terms of pre-deployment research a fairly wide expanse of work has been carried out on the assemblages of demersal fish on the Northern Japanese continental shelf, using mainly trawling techniques on flat bottoms as a sampling method. However, it was only since the deployment of the reef, that "demersal fishes have been periodically sampled" (Fujita *et al.*, 1996). Therefore, greater rigour in the pre-deployment sampling was required in order to fully develop an understanding of the impact of the Okama artificial reef on community composition, and also provide some degree of historical control.

The study by Fujita *et al.* (1996) provided a good example of a quantitative study, providing information on the species composition between the three sites using catch rates, both in terms of number of species caught and number of individuals caught, comparing both site and annual overall catch rates. However, there was a tendency towards sampling bias by the trammel net, in that cryptic species tended to be under represented in the sample. This was recognised by the investigators, who stated that "catch efficiency for each fish should be taken into account in future works to obtain precise and quantitative data of the artificial reef fish community" (Fujita *et al.*, 1996), although it could be asked why this was not undertaken in the published study?

The paper by Fabi and Fiorentini (1994) provides a further study comparing an artificial reef site with a control site, over a four year period from 1988 to 1991. The artificial reef was constructed of 29 pyramidal structures, built from cubic concrete blocks. These were deployed in October 1987, along with four concrete cylinders and 12 concrete cages. The control site was an area of mud bottom, of similar depth to the reef site (10-11m), located 2.5 miles from the artificial reef, to maintain independence. Two survey methods were used, the first being a quantitative study using trammel net sampling and the second a more qualitative visual census by SCUBA divers.

Again in this study the investigation suffers from the lack of replication. If several independent artificial reefs had been established, and compared with a similar number of control sites, the data obtained would definitely be considered more reliable. However, because the experiment describes only two sites, with no real pre-deployment research, the impact of the reef deployment on species richness and abundance is largely speculative. Yet again it must be asked if the correlation between the conclusion and the results actually demonstrates a causative link, but as the objective of the investigation was the comparison of the sampling gear this did not prove a major problem.

The comparison of a quantitative trammel net survey with the more qualitative diver survey provided an interesting assessment of techniques, showing that both tended towards a bias, with the divers often missing sandy bottom, benthic fish species, and the net often under-representing cryptic reef dwelling fish (e.g. *Conger conger*). However, a well designed diver survey, involving either a transect counting technique or some form of timed count, for example the Visual Fast Count method (Kimmel, 1985), would have allowed a more quantitative diver survey to be undertaken, and thus perhaps provide a more meaningful comparison with the trammel net.

In both these studies it is clear that the economic expense of artificial reef use in the research is one of the major factors affecting the work. In both cases lack of replication of artificial reef structures was the limiting factor on the experimental design. This is likely to be because, as in Charbonnel *et al.* (2002), the reefs used were deployed to fulfil a particular goal other than scientific study. Therefore, the researcher is forced to compromise from the outset in order to maintain a cost-effective study and so must design their studies according to the limiting factor which is the number of artificial reefs available to them.

Colonisation and faunal aggregations on artificial reefs

Studies of the colonisation of artificial reefs, and examination of the faunal assemblages, in particular reef fish, have proved important in progressing the scientific understanding of marine ecology. Two studies were examined. One study examined the fish assemblages which developed on an artificial reef, in an estuarine environment in the Gulf of Mexico (Bortone *et al.*, 1994), and the other study examined the colonisation of an artificial reef complex deployed in Poole Bay, United Kingdom (Jensen *et al.*, 1994).

The work carried out in the Gulf of Mexico by Bortone *et al.* (1994) involved deploying twelve conical plastic reef modules, in four groups of three, into the Choctawhatchee Bay estuary, at a depth of 6.5m. These were surveyed by SCUBA divers using a point-count visual census method, over a 13 month period, commencing in October 1987 and continuing until October 1988. Each reef complex was surveyed once per month, over the 13 months, including 1 pre-deployment survey, so that a total of 52 surveys were undertaken over the study period.

This study examined the number of species, species abundance, fish length, biomass and species diversity. Additionally sediment samples were collected, in order to calculate mean grain size and weight, and this and other independent variables recorded. The statistical analysis of the data collected included analysis of variance (ANOVA) and stepwise linear regression.

This study provides a relatively well designed experiment, with replicates of the reefs nested together. Two different sizes of cones were deployed, and these were thus replicated within the experimental model. One feature not really considered was a control. However pre-deployment research had been carried out, and so this could be used reasonably effectively as a historical control. The study provides another design problem because of the close proximity of the sets of reef units, which are separated by only 30m of sandy bottom. Thus the individual reef units cannot be considered as independent units and so the study is based on pseudoreplicated data (Hurlbert, 1984). An issue not acknowledged by the authors.

Perhaps more pre-deployment research could have been undertaken at the sites before the deployment of the reef, as this would have allowed the impact of artificial reef deployment upon the fish aggregations of an estuary to be examined more effectively. However the study does fulfil its primary goal by assessing the factors which affect the fish aggregations associated with artificial reefs in a disciplined and quantitative manner. The visual census technique involved a diver using video/audio on 5 minute sweeps of a 5.64m diameter circle, thus providing an easily quantifiable source of data.

In terms of cost-effectiveness the study by Bortone *et al.* (1994) makes good use of the resources available, with a high number of results obtained over the 13 month study period. However, further investment in the experimental design and the deployment of more than one reef complex, would have provided a better degree of independence, and thus a true replicated design.

The study by Jensen *et al* (1994) provides a good example of the study of artificial reef colonisation using a reef which was designed to ensure a high degree of replication. The study was carried out on an artificial reef in Poole Bay deployed at a depth of around 10m below chart datum. Monitoring of the epibiotic colonisation of the reef started soon after its deployment in 1989, using photography and examination of monitoring stations on each reef module by scientific divers. Studies of the common lobster (*Homarus gammarus*, Linnaeus) and the edible crab (*Cancer pagurus*, Linnaeus) were carried out by a modified tag-recapture technique, with re-observation by divers, and acoustic tracking used. Fish studies, involved underwater videography and photography used to estimate population abundance and size of individuals, and sampling of the infauna, was carried out prior to deployment and intermittently between May 1990 and July 1991.

Within the study by Jensen *et al.* (1994) a reasonable degree of replication was achieved through the reef design, with 8 reef units being deployed. Of these 8 units, 2 replicates each of three different PFA/gypsum mixes were deployed, and two control units made of concrete. This design allowed the researchers to consider each module as an independent sample site. However, the fact that all reef modules were deployed in one area, causes a problem. The reef had been designed so that each module is a mere 10 metres away from any other reef module. Evidence of any treatment effect, for example the impact of the reef material upon colonisation, could only really be applied to the Poole Bay site without the data being pseudoreplicated. This is because of one of the definitions of pseudoreplication is, "the testing for treatment effects with an error term inappropriate to the hypothesis being considered" (Hurlbert, 1984), and so pseudoreplication is an issue which need to be carefully considered in studies of this kind.

More pre-deployment research could have been undertaken, by Jensen *et al.* (1994). This is particularly noticeable in the lobster studies, where lobster pots could have been used to sample the area, and thus begin the tagging study prior to the reef deployment, allowing the reefs impact on the lobster populations in the local area to be assessed more effectively. Also the infaunal survey suffered by having only one set of samples collected, in May 1989, prior to the reef deployment. This provides a blatant example of lack of replication in the study design, because given that the variable under test here is the impact of the reef on the infauna, one set of samples does not provide a sufficient and balanced picture of the infauna prior to the manipulation.

From the perspective of quantifying the results this study was fairly effective in the main study areas, and some qualitative data was also obtained, through the observation of reproductive/mating behaviour, and eggs laid on the reef. Thus overall a fairly effective investigation was undertaken by Jensen *et al.* (1994), and despite the initial high cost associated with the deployment of the reef, a cost-effective study was undertaken, successfully bringing together several of the main features of artificial reef colonisation. For example, their work examined the effect of reef material on epibiotic colonisation, the effect of the reefs on commercially important crustaceans (*Homarus gammarus,* Linnaeus and *Cancer pagurus,* Linnaeus) and the seasonal patterns associated with colonisation. Also the reef itself continues to provide a resource for scientific research and so the benefits associated with this should be offset against the cost.

DISCUSSION

The study of artificial reefs by scientists can be a problematic affair, which need to be carefully balanced with other interest groups, the goals of the artificial reefs and basic economics (Sayer & Wilding, 2002). This results in scientists having to make compromises, which can often affect the experimental design of their studies. This is clearly observed in the papers that were reviewed and should serve as a warning to scientists in the planning stage of any artificial reef based experiment or investigation.

In particular it was noticed that the papers reviewed often suffered from a lack of replication. This was observed most notably in the studies by Charbonnel *et al.* (2002), Fujita *et al.* (1996) and Fabi and Fiorentini (1994), where only one replicate of each test site were sampled. This causes problems in the analysis of data, because it is purely an examination of the effects on a given number of discrete sites, and so begs the question, can we apply these conclusions to artificial reefs as a whole?

In terms of pre-deployment research it was often found that prior to the deployment of an artificial reef (Jensen *et al.*, 1994), or a manipulation of an experimental reef site (Charbonnel *et al.*, 2002) that an insufficient number of samples were taken. This is most note worthy in Jensen and his colleagues work (1994), where only one set of infaunal samples were taken, and little research was mentioned on the fish and macro-invertebrate assemblages prior to reef deployment.

The level of quantitative data displayed by all five papers was high, and this indicated that quantitative studies are easily achievable in ecological field experiments of the type carried out on artificial reefs, with two of the papers also providing qualitative study. In the paper by Fabi and Fiorentini (1994) the quantitative trammel net survey was compared and contrasted with a fairly simple qualitative survey by SCUBA divers, which helped to show the bias of the trammel net against many cryptic species. Also in the paper by Jensen *et al.* (1994) some qualitative results were displayed for the number of species observed exhibiting courtship behaviour and mating, as well as any eggs observed, and this helped to provide some direction to a future investigation.

Overall in the reviewed papers the experimental design can be seen to have been inhibited mainly by the economics of artificial reef research. For instance the level of replication and quality of the experimental design was observed to be higher in the two studies which involved the deployment of experimental artificial reefs (Jensen *et al.*, 1994; Bortone *et al.*, 1994). However, in these cases the fact that the reefs were deployed in a very concentrated area caused problems. These problems are not easily resolved as reef deployment may interfere with other interest groups, e.g. the fishing industry, and may adversely affect an area of habitat, so the licensing issues of deploying a number of highly replicated reefs are likely to be prohibitively expensive and unrealistic. Further to this all the investigators would have been bound by a finite number of days when sampling work could be undertaken, because of weather, availability of ship-time, availability of divers, and the limited financial resources. As a result compromise was inevitable, and so it is easy to see how the problems highlighted by this paper arise.

In terms of "making a difference" the use of artificial reefs is effectively still in its infancy and yet their applications are already widespread, ranging from protection and aggregation of fish stocks, as an aid to the regeneration and sustainability of commercial fisheries; the mitigation of environmental damage, from as diverse sources as power stations and fish farms; to their widespread use as attractions for leisure activities, be it surfing, SCUBA diving or recreational fishing; and new applications are to be expected (Jensen, 2002).

The increased interest in artificial reef technology can only serve to expand the related scientific opportunities, as demand for increased knowledge of the functionality of reefs, and their impacts is required. However the future study of reefs will often require a multi-disciplinary approach, in order to gain a full understanding of their hydrographic, ecological and socio-economic effects and, as such the potential for scientific study should be included in the goals of any new reef, thus providing further sites where effective study can take place.

Currently the understanding of how artificial reefs impact upon the receiving environment is a limit on design, both through the disturbance caused and also through the enrichment of marine benthic habitat. It is recognised that artificial reefs are unlikely to significantly increase global marine biodiversity (Wilding & Sayer 2002a); but there is still debate over their local effects. This is largely caused by questions about the aggregation of organisms at artificial reefs, and their input back into the larval stream. The so-called attraction-production controversy (Osenberg *et al.*, 2002). In order to resolve this, several factors need to be investigated.

Firstly the effect of reef scale needs to be examined, to determine what size of reef will support a stable breeding population of a given species. This will be a difficult study to carry out because of the problems of replicating reefs on a larger scale, in terms of cost and complexity. Secondly more work needs to be carried out to establish the similarities and differences between artificial and natural reefs, by studying the similarities and differences in the community composition and relative abundance of species at a number of artificial and natural reef sites. As a result of this research, a greater knowledge of the effects an artificial reef has upon its local environment will become available. The result being the refinement of the present artificial reef applications, and a strong scientific base on which new uses for artificial reef technology can be researched and developed.

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